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The Effect of Information on C2 Cognitive and Network Capabilities

by Jeffrey T. Hansberger

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14. ABSTRACT
One of the challenges faced by the Army and other U.S. military services, including the Joint Forces Command, is getting the right information to the right individuals at the right time. General James E. Cartwright, U.S. Marine Corps, highlighted this point before the Strategic Forces Subcommittee on Space Policy, 16 March 2005, as he stated, "Critical information that the warfighter didn't know existed and the owner of the information didn't know was important must be made available within a global information environment easily accessible to commanders at all levels."
The challenge of critical information dissemination applies to the Soldier in the field who requires information and feedback relevant to his/her mission and up the command chain to the commander who is trying to understand and make decisions at an operational level. The challenge of getting the right information to the right people when they need it is also relevant to military missions other than warfighting. Hurricane Katrina relief efforts in 2005 emphasized the importance of effective communication and collaboration as National Guard Soldiers and active component Army Soldiers assisted other state and Federal agencies. The information age in which the Army operates and conducts warfighting, personnel recovery, and disaster relief missions requires an understanding of the information domain, how information propagates through an organization, and the effects it has on distributed and co-located human behavior and cognition. This project uses a unique combination of human performance modeling, social network analysis, and experimentation that adds to the understanding of information flow within the command structure.

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1. Objectives

The objective of this research study was to investigate how information dissemination can be improved through the Army chain of command and beyond to include other services and the Joint Forces Command. A unique combination of human performance modeling, social network analysis, and experimentation will help us understand the effects of information flow within the command structure. This included an examination of the effects at the command and control (C2) human performance individual level and the overall organizational level.

2. Approach

The research approach for this project integrated past C2 research to provide the theoretical basis to apply the use of human performance modeling, social network simulation and analysis, and experimentation within a simulated C2 research environment. Each of these areas is discussed in turn regarding its application to C2 and the results for each area.

2.1 Human-Centered C2 Theoretical Framework

The area and study of command and control have been described as convoluted, idiosyncratic, and lacking focus because of the complexity and breadth within C2 (Crumley and Sherman, 1990). Although many contemporary C2 theories focus on organizations and communications, there is a strong case that much of C2 is about the cognitive processes of the individuals involved (Builder et al., 1999; McCann and Pigeau, 2000). Part of this Director's Research Initiative (DRI) work was dedicated to reviewing the current state of C2 theories and bringing together C2 research from the academic and operational areas with a central focus on humans and their cognitive capabilities.

The use of network representations for developing theories and knowledge relationships has been done across many domains in the form of related concepts with linking phrases representing the relationships between concepts. Concepts are defined as "perceived regularities in events or objects, or records of events or objects, designated by a label" (Novak, 1998). Graphically representing the concepts and their relationships in a concept map enables the expression of knowledge in a form easily understood by others. There is strong evidence that the creation of concept maps facilitates learning and understanding in its targeted domain or topic (e.g., White and Gunstone, 1992).

2.2 C2 Simulated Research Environment (C2-SRE)

Continued examination and study of a complex concept such as C2 require appropriate research tools and environment to investigate the relevant complex and dynamic issues. A C2-SRE was

needed for this project and continued research efforts that did not require a large technical support footprint to set up and run and cover the C2 dynamics between the tactical and operational levels, within and across services. The simulated environment produced by Mosbe Software of Breakaway, Inc., was used for scenario development and was prepared for experimentation.

The Mosbe software is a simulation toolkit to rapidly develop and deploy customizable two-dimensional (2-D) and 3-dimensional (3-D) simulated environments for experimentation and analysis purposes (figure 1). The simulation supports multiple individuals adopting different C2 roles within the scenario. The players accomplish the mission objectives of the scenario through their interactions with the simulated environment, enemy forces, and other human and/or simulated friendly forces. C2 related data collection capabilities were added to the simulation in order to improve its use as a research environment for the investigation of C2 issues outlined and defined from the human-centered theoretical framework.

Figure 1. (a) Mosbe simulation, 2-D view, and (b) Mosbe simulation, 3-D view.

2.3 Modeling and Simulation

The use of human performance models aids in the preparation for human-in-the-loop experimentation by allowing the examination of various effects before timely and costly experimentation and the precise definitions of many components required for a computational model that is often overlooked or undefined otherwise. The command, control, and communications: techniques for the reliable assessment of concept execution (C3TRACE) modeling architecture (Hansberger and Barnette, 2005; Plott et al., 2004) developed by the U.S. Army Research Laboratory (ARL) was used to model C2 human performance at the individual and organizational levels. C3TRACE is a task network model that can represent different

organizational structures, individuals within those structures, the tasks and functions performed within a task, and the communication patterns between individuals in an organizational structure. The modeling environment consists of a user-configurable graphical interface to manipulate the model parameters and settings and uses a discrete event engine (Micro Saint Sharp) to drive the simulation. C3TRACE provides feedback about a number of different human performance variables such as communication, decision-making quality, workload, situation awareness, and time on task. The three primary input categories are the organizational structure and entities, the functions and tasks individuals are responsible for, and the communication events. Each of these defines the task and allows for various manipulations within the modeling environment.

Another simulation component that complements the human performance modeling is the simulation of various network configurations. Multiple network analysis simulation and analytical tools were employed to examine network communication vulnerabilities. These efforts have also acted as the springboard for current and future work with ARL's Computer Information Systems Branch to integrate network analysis tools with the C3TRACE modeling architecture.

2.4 Network Analysis and Assessment

The network analysis and assessment across multi-regional city emergency response teams was conducted to examine the C2 interactions between the regional units and individuals. Communication networks and patterns across four regional emergency response teams were collected and analyzed over a 3-day live exercise. The C2 challenges across regional units and resources responding to a hazardous materiel incident share many similarities with military personnel and teams attempting to coordinate and conduct effective C2 practices within and across military services. Because of project time limitations, the human-in-the-loop experiment using the C2-SRE, model results, and the scenario designed was rescheduled for 2008.

3. Results

3.1 Human-Centered C2 Theoretical Framework

A theoretical framework for human-centered C2 was developed from a review of academic and military sources. This review identified four primary areas related to human behavior and cognition including the (a) C2 environment (figure 2), (b) C2 decision making, (c) C2 information, and the (d) C2 organization. Each of these areas is represented in the human-centered C2 concept map that aids in establishing the relationships, within and between each of these areas and presented in a brief summary next.

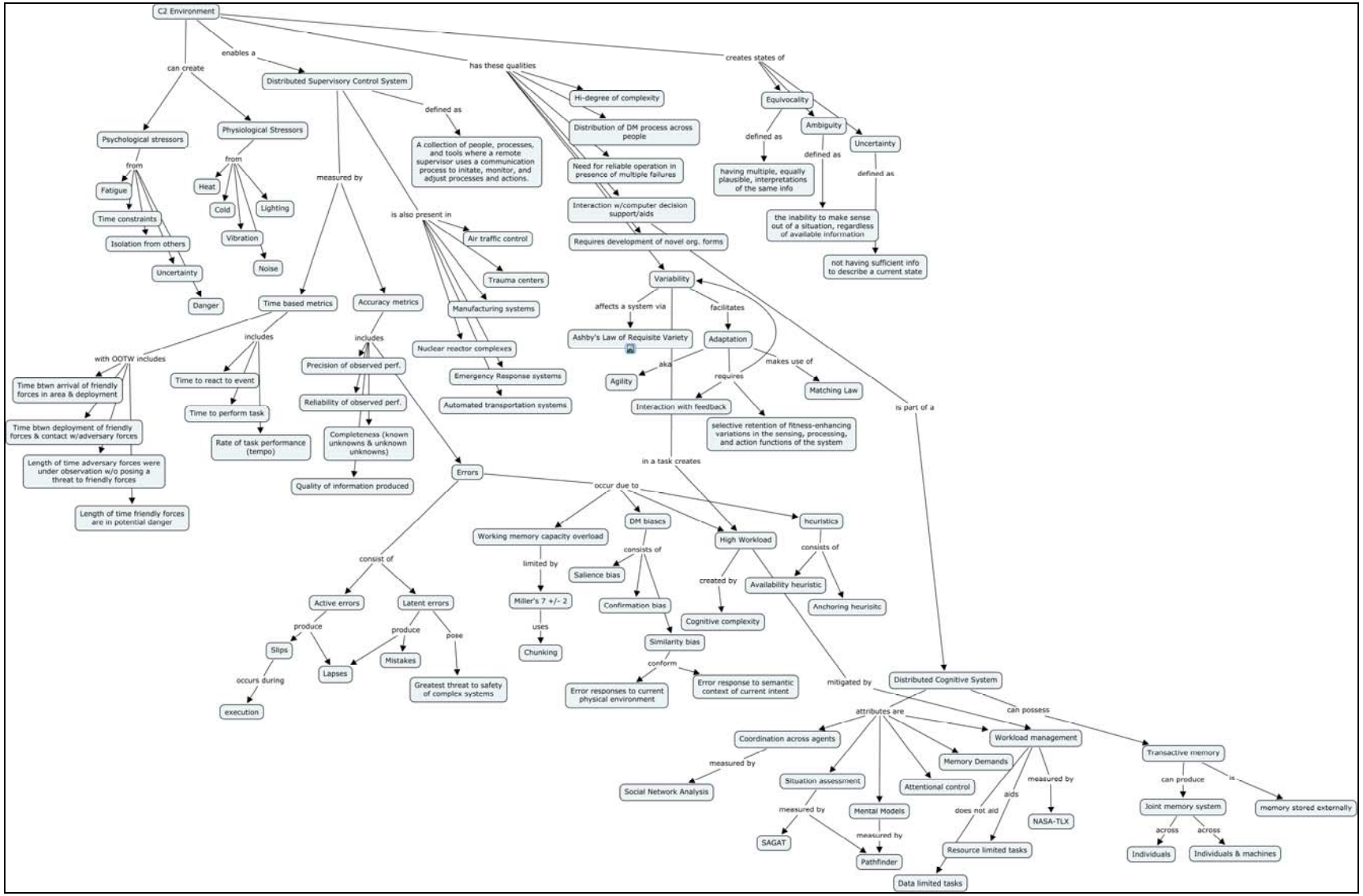

Figure 2. Concept mapping of one of four of the human-centered C2 areas, the C2 environment (shown without linkages to the other three areas).

3.1.1 C2 Environment

The C2 environment frames and influences most C2 behavior through a number of common characteristics such as the environment possessing a high degree of complexity, variability, the distribution of decision-making processes across people and the interaction with computer decision support/aids, to name just a few (Athans, 1986). These common characteristics are also found in other domains such as air traffic control, nuclear reactor complexes, and emergency response teams and have the same requirement for C2 capabilities. All these instances of C2 can be viewed and analyzed as a distributed cognitive system which goes beyond the cognition of a single individual and focuses on the functional system as a whole to examine the relation among individuals, the task environment, and artifacts used for task completion. Among one of the elements of a distributed cognitive system is how commanders and staff make decisions using technology within their very dynamic environment.

3.1.2 C2 Decision Making

The field of decision making has been given considerable attention within (e.g., Crumley and Sherman, 1990) and outside (e.g., Klein et al., 1995) the military. Most decision making can be broken into two primary categories of non-dynamic (e.g., planning and pre-contact activities) and dynamic (post-contact activities) decision making. Many military decision making models for dynamic decision making exist such as the Observe, Orient, Decide, Act/Dynamic OODA (OODA/DOODA) loop (Boyd, 1987; Brehmer, 2000), the stimulus-hypothesis-option-response (SHOR) model, and the control theory model (Lawson, 1981). To better understand, expand, and experiment with possible derivations of and improvements in these operationally oriented models of decision making, their theoretical origins and relationships to other cognitive decision-making models must be identified and understood. The concept mapping of the military decision-making models and cognitive theories of decision making begins to illustrate these relationships and shows the vital link between decision making and C2 related information.

3.1.3 C2 Information

The review of information and its use within C2 processes identified many ways to categorize information that should greatly aid in its study and manipulation. One of the more general distinctions among C2 related information is that it can be situation independent or dependent. The situational dependence or independence of information has a large influence on how the acquisition and use of that information is measured in experimentation. Another element that plays a central role is how the commander translates available information and communicates that to his staff in the form of commander's intent. This process of communicating commander's intent is one of several key and fundamental C2 functions identified in the last human-centered C2 area, the C2 organization.

3.1.4 C2 Organization

The organization of the processes and personnel within a service, across services, and across nations in multi-national efforts can have a large influence on C2. Whether the organization operates in a centralized or decentralized fashion, it should perform some or all of the general C2 functions identified by Van Creveld (1985). These C2 functions include tasks such as planning, gathering information about relevant areas, and developing objectives and alternatives, to name a few. The effectiveness of each of these C2 functions is in turn a product of the structure, functional organizational differences, and capacity of the work force and system.

3.2 C2-SRE

An urban scenario set in Baghdad, Iraq, was designed and created with a simplified representation of the command structure from the Joint Task Force to company level for the Army and Marines. The objective at the lowest level is to locate and communicate important aspects of the virtual urban environment such as insurgents and improvised explosive devices (IEDs). The simulated upper echelons must receive, integrate, and react, based on the new information and their other mission objectives. Six total scenarios were created to support a scenario difficulty manipulation with three easy and three difficult scenarios. These scenarios are considered isomorphic and functionally the same since they maintain the same difficulty levels but change the locations of the enemy units. This basic scenario that forces communication among multiple players within and across services and through a number of echelons will be the base scenario to support future C2 experimentation for years to come.

3.3 Modeling and Simulation

A complete C3TRACE model was created that defines each task of every position represented in the experimental design with the C2-SRE and the information flow for the easy and difficult conditions represented during scenario creation. The task and information flows for each echelon represent the types of information, decisions, and actions required for the overall mission. From a human performance workload perspective, the battalion level echelon possessed the highest overall use and workload regarding task and information requirements. The initial creation of this model has been a useful first step in the preparation for further model refinements and will provide valuable experimental information throughout the model-test-model paradigm.

The C3TRACE modeling was complemented by network simulations of the standard information dissemination structure from the tactical to operational echelon levels. The KeyPlayer network analysis program identifies important and vital nodes within a network that if impaired, could dramatically impair the network as a whole. Based on the network concepts of fragmentation (the number of sub-networks created if the target node is impaired/eliminated) and communication distance (the distance communications must travel or be re-routed through if the target node is impaired/eliminated), the battalion level echelon (for the Army and Marines) was

identified as a critical level for information dissemination. The input of this human performance model and network simulation of critical C2 elements will continue to play a critical role of C2 work being done at the ARL Joint Forces Command Field Element in Suffolk, VA.

3.4 Network Analysis and Assessment

To examine social network properties of a distributed multi-team/service communication structure similar to those described and captured in the C2-SRE, communication data were analyzed from a live 3-day emergency response exercise across city resources and teams. The communication network for each day's exercise is displayed in figure 3. Each node represents a player within the exercise, and the links represent their reported communications with other players. The nodes are colored according to the players' city affiliation across the four cities that were involved in each exercise.

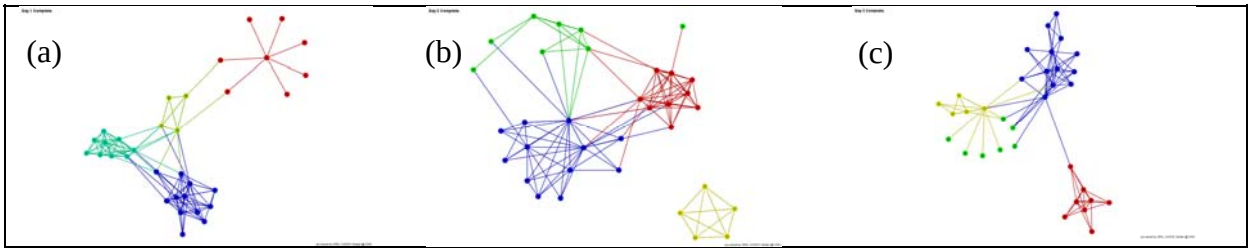

Figure 3. Network illustration of the communication structure within each exercise. (Figures 3a, 3b, and 3c represent communications during days 1, 2, and 3.)

The consistent structure across each of the exercises (figure 3) displays each of the cities as clusters loosely connected to each other. This network structure is representative of a cellular network structure comprised of quasi-independent cells (i.e., cities) and distributed command. This structure is in contrast to a traditional organizational structure that is more hierarchically structured. Cellular networks are typically very adaptive, well suited for volatile and dynamic environments and capable of rapid response. For these reasons, the cellular structure often represents covert networks such as terrorist organizations (Tsvetovat and Carley, 2005).

Further analysis of the network structures reveals very distributed networks for the intra-team/city networks, which represent the cells in the larger cellular network structure. These distributed networks are known to be effective for rapid, small-scale decision making, very adaptive to changing situations, and well suited for complex environments. Distributed networks are often present within special operations teams in the military and appear to be an appropriate and advantageous for local emergency response teams.

4. Conclusions

In addition to the work done on a theoretical model of human-centered C2, the establishment of a simulated research environment and scenarios for C2 experimentation, the construction of a C3TRACE human performance modeling and use of network simulation, and the C2 assessment of network structures and capabilities, this DRI work has driven efforts in several other areas. The C2 human-centered theoretical framework has been used to acquire the C2 analysis and assessment lead position for two Defense Advanced Research Projects Agency projects (Conflict Modeling, Planning, and Outcome Experimentation [COMPOEX] and Deep Green). The C2-SRE efforts have initiated a multi-year symposium effort with academic, military, and industrial members in the Behavioral Representation in Modeling & Simulation conference. The C3TRACE and network simulation work has initiated additional funding to integrate C3TRACE with dynamic network analysis tools for greater ease in modeling and analyzing human performance and network data. Finally, all the efforts have created the theoretical and experimental foundation to address current and future C2 research and design challenges for commanders and war fighters in the Army and the Joint Forces Command.

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